Spatial Computing: Defining the Vision for the Future

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ABSTRACT

Spatial Computing integrates technologies like Mixed Reality, Artificial Intelligence, and the Global Positioning System, enabling immersive, natural, and intelligent multi-modal interactions in physical and virtual spaces. With the huge potential to benefit users in multiple scenarios (e.g., gaming, education, design, and healthcare), Spatial Computing is growing at an incredible rate, with different attempts to define and capitalize on the growth in both industry and academia. Beyond the location, shape, and relationship of geographic objects, Spatial Computing delves into the social, emotional, and cognitive dimensions of shared spaces. However, the human-computer interaction research on Spatial Computing faces a notable gap, particularly in user experience areas like collaboration, trust, ethics, and accessibility. Addressing this gap, this Special Interest Group (SIG) seeks to unite experts from academia and industry to explore current and future trends in Spatial Computing.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

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KEYWORDS

Spatial Computing, Artificial Intelligent, Mixed Reality, Augmented Reality, Location-based Media, Human-Computer Interaction, Special Interests Group

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1 INTRODUCTION

> *An architect, Y, starts the day by putting on a pair of glasses. Wearing the glasses, Y can view 3D architectural models during breakfast. While navigating to the office, navigation prompts overlap with the real-world roads. In a remote meeting, virtual avatars of Y's team collaborate on designs. By the end of the day, Y talked to the AI assistant incorporated in the glasses and asked their advice for dinner recipes...*

This may seem like a scenario from a sci-fi film, but it will become a reality soon, enabled by Spatial Computing. Spatial Computing encompasses a range of technologies (e.g., Mixed Reality, Artificial Intelligence, the Global Positioning System, Mobile Technologies, Networks, etc.) that enable immersive, natural, and intelligent interactions in our physical and virtual spaces, which can benefit users in multiple scenarios (e.g., gaming, education, design, and healthcare [7, 15]). Beyond dynamic visual content overlapping the real world, Spatial Computing experiences can also involve multiple modes of interaction, such as audio, haptic, and gesture-based interfaces.

In industry, many tech companies, such as Apple, Microsoft, Google, and Meta, are investing in Spatial Computing and developing new devices (hardware) and applications (software). Specifically, the Spatial Computing Market size was valued at USD 97.9 billion in 2023 and is anticipated to grow to USD 280.5 billion by 2028 [14]. One of the pioneers in this Spatial Computing area is Apple, which plans to launch its revolutionary spatial computer Apple Vision Pro[1] in 2024. Apple Vision Pro will feature spatial audio, two micro-OLED displays, the Apple R1 chip, and eye tracking. This product aims to bring new possibilities in absorbing, creating, and sharing information in our hybrid space through multi-modal interactions. It is expected to create a new wave of human-computer interaction and thus bring Spatial Computing to the forefront of discussion.

In academia, especially in Geographical literature, Spatial Computing is not a newly emerged term. One of the pioneers in this field, Simon Greenwold [2003], defines Spatial Computing as "human interaction with a machine in which the machine retains and manipulates referents to real objects and spaces." In other words, initially, Spatial Computing emphasized understanding and analyzing our *physical* space (i.e., the real world), which was implicated with several technologies, including the Global Positioning System (GPS), Remote Sensing, Geographic Information System (GIS), Spatial Database Management System, and Spatial Statistics [17]. Specifically, these technologies opened up the following user scenarios:

- GPS: It helps users know "Where am I on the surface of the planet" and thus enables a series of location-based services and media (e.g., Uber[2], Google Maps[3]);
- Remote Sensing: It helps users monitor and understand the changes in land cover, such as climate change and urbanization. Remote sensing satellites (e.g., MODIS[4], Landsat[5]) can also help users explore and discover the hidden resources beneath the land surface, such as water and minerals;
- GIS: It helps individuals and organizations better understand spatial patterns and relationships, such as the location of pollution sources and sensitive areas, the distribution of population and income, or the optimal routes and sites for transportation and services.
- Spatial Database Management System: It is a system that can store, manage, and analyze spatial data, which are data that have a geographic component, such as location, shape, and relationship.
- Spatial Statistics: It involves a series of theories and techniques to address these challenges and to model and analyze spatial data, such as point processes, spatial autocorrelation, geostatistics, spatial regression, spatial interpolation, spatial clustering, spatial sampling, and spatial visualization.

[1]https://www.apple.com/apple-vision-pro
[2]https://www.uber.com/
[3]https://www.google.com/maps
[4]http://modis-land.gsfc.nasa.gov/
[5]https://www.usgs.gov/landsat-missions

As the boundary between virtual and physical space has blurred [12, 16], our understanding of "space" has expanded from *physical space* to *hybrid* space [4]. Accordingly, the context of Spatial Computing is evolving, extending from the "understanding of the physical space" to "exploring the hybrid space." Meanwhile, a growing series of developing technologies are innovating Spatial Computing:

- Artificial Intelligence (AI): It can assist users in understanding space in various ways. AI chatbots (e.g., Open AI GPT-4[6], Microsoft Bing Chat[7]) are good examples. These large language model networks are aware of the space and context we are located in, performing tasks including answering questions, providing recommendations, and so on.
- Mixed Reality (MR): It includes Virtual Reality (VR) and Augmented Reality (AR), developed rapidly in the past decade, which brings possibilities for creating computationally mediated immersive content overlapping/in our physical space [2, 3].
- Mobile Computing (e.g., mobile phones and wearables): It allows users to constantly connect to the Internet while moving through physical space and bring virtual social content into physical space [4].
- Robotics: It enables computers to blend in with the physical world naturally through multi-modal input and output (e.g., gesture, eye-tracking, haptic, etc.), using computer vision, sensor fusion, spatial mapping, and other techniques, and thus support human-robot interaction [10, 11].
- Massive fictional worlds like *Final Fantasy XIV: A Realm Reborn* or *World of Warcraft* have been experimenting with how maps in games could and should function, leading to new inquiries into how a game cartography interface should immerse users even inside of worlds that do not exist [13, 18, 19].

Although some of the technologies listed above are still nascent, there is vast potential for how Spatial Computing could transform and enhance how we perceive, share, and create in physical and virtual spaces. For example, mobile AR location-based games (e.g., Pokémon GO[8]), which combine MR, Mobile technology, and GPS to create augmented environments that are spatially aware and responsive [1]. Take another example: combining Robotics and MR enables novel use cases such as mission planning for inspection, gesture-based control, and immersive teleoperation [6]. These instances showcase the interdisciplinary essence of Spatial Computing, emphasizing the extensive potential for crafting innovative experiences through the seamless integration of various technologies.

2 MOTIVATION

Spatial Computing is poised to revolutionize our lives in various ways: it can enhance our perception and cognition and provide entertainment and education in the hybrid space. Instead of being an individual's experience, Spatial Computing can also affect how we interact and socialize with others in a shared space [3]. In other words, Spatial Computing is an evolving field that goes beyond the

[6]https://openai.com/research/gpt-4
[7]https://www.microsoft.com/en-us/edge/features/bing-chat?form=MT00D8
[8]https://pokemongolive.com/?hl=en

location, shape, and relationship of geographic objects and encompasses space's social, emotional, and cognitive aspects. Recognizing the need for a human factors perspective, Spatial Computing invites understanding through the lens of how users interact with systems, optimizing human performance, well-being, and satisfaction [20]. This approach can address challenges and seize opportunities, including usability, accessibility, privacy, ethics, and social impact.

However, most extant Spatial Computing studies are conducted from a technological perspective (e.g., [5, 8]). Consequently, there is a shortage of human-computer interaction research on this topic. In other words, the human factors of Spatial Computing, such as user experience, ethics, and accessibility, are largely overlooked and underdeveloped. To this end, we lack an understanding of how users will interact with Spatial Computing applications and what challenges they will face.

Furthermore, the future trends and directions for Spatial Computing are unclear and uncertain. We propose this SIG as a platform for researchers, practitioners, and enthusiasts who share a common interest in Spatial Computing to discuss this area from a socio-technical perspective. This SIG will facilitate collaboration, networking, and community building among the participants.

3 OBJECTIVES

We aim to bring together three types of experts who are interested in Spatial Computing: those who work on the technological aspects (e.g., AI scientists, XR developers, etc.), those who work on the human aspects (e.g., user experience designers, social scientists, etc.), and those who integrate both (e.g., human factor engineer, accessibility engineer, etc.). We will ensure the diversity of the attendees regarding gender, cultural background, and age and encourage interdisciplinary discussions. In this Spatial Computing SIG, we have several open questions to explore:

(1) What are the existing applications of Spatial Computing? How do they influence both individual activities and collaborations from what aspects?
(2) What are the future user scenarios and use cases of Spatial Computing?
(3) What are the foreseeable challenges for users, designers, and developers in Spatial Computing?
(4) What are the best practices and guidelines for designing Spatial Computing applications? In other words, how can we ensure that Spatial Computing is inclusive, safe, and efficient?

We welcome diverse opinions, respectful dialogues, and constructive debates.

4 SIG FORMAT

This SIG will follow the hybrid format of CHI this year, allowing both online and in-person participation. We will use Miro Board as the main online platform to support the hybrid collaboration. Miro Board is a visual collaboration tool that allows users to create, share, and edit interactive boards with various media and features.

We will project the slides, media, and Miro board on a screen for the in-person attendees. The online attendees will join a Zoom session, where they can see and hear the projected content. They can also access the Miro board directly from their devices and interact with it in real-time. This way, both in-person and online attendees can communicate seamlessly and collaboratively through the Miro board and the Zoom session.

We will begin the SIG by giving a brief overview of the concept and history of Spatial Computing, emphasizing how it has evolved and why it is important to discuss it from an HCI angle. Then, we will group participants (break-out rooms for online attendees) into three topics: **Current applications, Foreseeable challenges, and Future trends** in Spatial Computing. They can use the Miro Board to brainstorm, share documents, sketch, and do other activities.

Each topic has at least one organizer to assist with the discussion and take notes when necessary. Attendees can change to other topics during the discussions when they feel they have enough ideas on the current one. Still, organizers will balance the attendees of each topic, ensuring they have a similar amount of participants. After the topic discussions, attendees can freely discuss all **open questions** (listed above).

The schedule is shown as follows (See Table 1):

Table 1: schedule for the main event

Duration	Activities
7 minutes	Opening and instruction
3 minutes	Slide presentation by the organizer
30 minutes	Topics discussion
20 minutes	Open questions discussion
5 minutes	Conclusions

5 EXPECTED OUTCOMES AND NEXT STEPS

Our SIG will have the following outcomes:

- We will produce a white paper that summarizes the main findings and insights from the SIG and make it available on social media and the website, along with the materials presented by the participants.
- We will write a research paper that synthesizes the research-related aspects of the SIG and submit it to a relevant conference such as ACM CHI and CSCW.
- We will propose a Special Issue at TOCHI or a similar journal that would benefit from a focused discussion of Spatial Computing with members of the SIG serving as editors for said special issue.

We also aim to use this SIG as a platform for building a community of HCI researchers and practitioners who are interested in Spatial Computing. This is an interdisciplinary topic that requires a lot of collaboration and coordination across different domains and perspectives. To facilitate this, we plan to do the following:

- We will keep in touch with the participants through our discord server, schedule biannual meetings, and encourage them to share their ideas, latest works, and feedback.
- We will use the knowledge gained from this SIG to design other activities (e.g., panels, grants, seminars, etc.) at other venues and conferences to foster more collaboration, expand the community, and advance the topic of Spatial Computing.

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